

**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

**PATENT APPLICATION**

**APPLICANTS/INVENTORS:** Bharti Temkin, Ransom Canyon, TX  
a U.S. citizen;

Kirk Watson, Round Rock, TX  
a U.S. citizen; and

Eric Acosta, Lubbock, TX, a U.S. citizen

**POST OFFICE ADDRESS:** c/o Texas Tech University  
Transfer and Intellectual Property  
P.O. Box 42007  
Lubbock, Texas 79409-2007

**INVENTION TITLE:** DEVELOPMENT OF STEREOSCOPIC-HAPTIC  
VIRTUAL ENVIRONMENTS

**ASSIGNEE:** Texas Tech University, a not-for-profit  
institution

**ATTORNEYS/AGENTS:** Perkins, Smith & Cohen, LLP  
Jacob N. Erlich, (Reg. No. 24,338)  
Jerry Cohen (Reg. No. 20,522),  
Stephen Y. Chow (Reg. No. 31,338)  
Harvey Kaye (Reg. No. 18,978)  
Christine M. Kuta (Reg. No. 38,001)  
One Beacon Street  
Boston, MA 02108  
(617) 854-4000 voice and fax 617-854-4040

Correspondence to Mr. Cohen  
617-854-4282 direct line  
E: jerry\_cohen@pscboston.com

**To:** Honorable Commissioner of Patents and Trademarks  
Washington, D.C. 20231

**Sir:** Your applicants, named above, hereby requests acceptance of the enclosed  
regular utility application entitled as stated above pursuant to 35 U.S.C. § 111(a).

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**DEVELOPMENT OF STEREOSCOPIC-HAPTIC VIRTUAL ENVIRONMENTS**  
**FIELD AND BACKGROUND OF THE INVENTION**

The present invention relates to apparatus and software cooperatively integrating haptic or touching and stereoscopic or three dimensional visual computer  
5 interfaces, and is more particularly associated with such apparatuses and software as applied  
to surgical simulations. The integration in computer generated virtual environments of  
interfacing of physically felt force-feedback devices (haptic interface devices) that provide  
the touch or feel sensation and stereoscopic visual interfaces that provide visual three  
dimensional (3D) objects have not been extensively developed. Those that exist use  
10 expensive complex and often ad hoc hardware and software that are difficult to implement  
and more difficult to service and/or modify. High end, expensive graphic workstations, e.g.  
Sun Microsystems with specialized hardware and/or software have been so used, but are not  
amendable to routine use due to the complexity and the expense.

Before proceeding some definitions will be helpful in understanding the invention.

15 HAPTICS: Haptics refers to touch. Human sense of touch, human haptics, differs  
fundamentally from other human sensory modalities in that it is bilateral in nature: to touch  
an object, the object must "push" back. In computer generated haptics, a computer interface  
device is used that provides a physical touch to the human that corresponds to the real  
three-dimensional sense of touch that allows one to feel textures and shapes of objects,  
20 modulate objects and even deform objects.

Two major components of computer haptics are collision detection of virtual objects  
with the haptic interface device, and the determination and application of a force feedback to  
the user via the haptic interface device. Prior art data structures and algorithms applied to  
haptic rendering have been adopted from non-pliable surface-based (two dimensional)  
25 graphic systems. These prior art techniques and systems are inappropriate and limited due

to the different characteristics required for haptic rendering of three dimensional or volumetric soft bodies.

STEREOSCOPIC DISPLAY: Stereoscopic herein refers to true 3D viewing of objects. In many prior art systems 3D images are rendered for viewing in a 2D format (e.g.,  
5 on a flat monitor). True 3D viewing provides the user with the appearance of true depth.

When viewing an object in 3D, both eyes see the object from a slightly different perspective. Each eye perceives a slightly different image, with the brain naturally fusing these two images into one by matching up the similarities and adding in the small difference. The result is the illusion of depth. This process of stereopsis can be simulated  
10 by 1) generating the two dimensional image for each eye, and 2) presenting the left eye image only to the left eye and the right eye image only to the right eye. This brief review suffices since stereoscopy is well understood in the art.

Such prior art devices are even more limited if applied to teaching the complex skills associated with medical surgery. Surgery skills are taught on live patients or animals. A  
15 computer system that provides true touch and corresponding 3D vision for volumetric soft bodies is needed in the art.

It is an object of the present invention to generate a stereoscopic-haptic computer interface suitable for providing virtual environment.

It is another object of the present invention to result in the illusion of being able to  
20 "see" and "touch and feel" 3D virtual environment, for example, a surgeon operating on a virtual patient, but with true-to-life touching and seeing.

It is yet another object of the present invention to produce cost-effective, real-time, interactive, stereoscopic haptic virtual environment with minimal hardware.

It is yet another object of the present invention to transform the virtual environment  
25 from a flat, formless 2D experience to a more realistic and solid 3D experience.

It is still another object of the present invention to provide 3D organ models for study by and training of students.

### SUMMARY OF THE INVENTION

The objects set forth above as well as further and other objects and advantages of the present invention are achieved by the embodiments of the invention described herein below.

The present invention includes generating a stereoscopic-haptic interface to simulate human sense of touch and depth perception with display 3D information in a flat 2D environment. The haptic interface and stereoscopic technologies include: 1) generating stereoscopic images using, active stereoscopic displays where shutter glasses shutter on and off in synchrony, interlaced video displays and a stencil buffer to draw images on different scan lines; and 2) making a stereoscopic-haptic system using a point-based haptic device, all with supporting software. The haptic environments are created independently of their graphical representations allowing for independent development and troubleshooting, but where the haptic and visual presentations are coordinated. The visual 3D is accomplished with a single camera that is moved to simulate the position of the left eye and then the right eye. The image in each position is stored in a stencil buffer that records the left eye image on even scan lines and the right eye image on the odd scan lines of an interlaced video system. The presentation of the two images via the shuttered glasses to the corresponding eye in a coordinated fashion and the coordinated haptic device allows for 3D visualization and corresponding touching to be experienced by the user in the virtual environment.

An advantage of the present invention is the operation without costly extra hardware and software as described above. The present invention uses the vertical synchronization signals directly from the video signal to switch the shutters on the glasses and the multiplexing of the left and right images by using interlaced scan lines minimizes complex and costly hardware and synchronizing software. The result is that the haptic and the 3D visual are combined with a minimum of extra hardware and software to provide a cost

effective virtual environment suitable for teaching and practicing complex, difficult techniques that depend on sight and touch.

For a better understanding of the present invention, together with other and further objects thereof, reference is made to the accompanying drawings and detailed description.

## 5 BRIEF DESCRIPTION OF THE DRAWING

Figure 1 is a flow diagram implementing a haptic application and interface device;

Figure 2 is a representation of left and right eye images combined to form 3D stereoscopic image;

Figure 3 represents parallax issues in 3D presentations;

10 Figure 4 is a parallel camera model;

Figure 5 is a flowchart of a preferred embodiment process architecture;

Figure 6 shows a scene with the stencil rendered, and

Figure 7 is a diagram of showing the independence of the haptic and visual representation.

## 15 DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Figure 1 is a flow diagram of implementing a programmable haptic pointing device in an environment that simulates human touch. The location, 3D shape, and feel of the object are programmed so that, when the user moves the interface device, the positional information in virtual space is retained, and based on what the object being touched (as programmed) the device provides a force feedback to the hand of the user.

Referring to Figure 1, the scene is initialized 2 as to the touch and shape of the objects in the scene and their virtual positions. The relative virtual position 4 of the haptic interface is determined. As the interface device is moved, the touching of the objects in the scene is determined by resolving collisions 6 with the virtual objects. Depending on the type of object encountered the interface device presents back 10 to the user a force calculated 8 to duplicate the force that an actual object would provide.

The force interaction of Figure 1 provides means for training of cognitive skills to users, but can also allow evaluations of sensory-motor skills; for example, an advanced haptic surgical simulation not only is capable of teaching the complex physical interaction skills, but, as mentioned above, also can record and play back the mechanical signals. This later feature can be used to monitor trainee's skill acquisition, customize the training program, or even let a trainee practice on prerecorded actions of an expert.

Figure 2 is a diagram showing the perspective binocular disparity between the left eye 12 and the right eye 14 when viewing a scene and the scene frontally shown. 16. This disparity provides the human brain 18 with information that is the stereoscopic 3 D effect.

Figure 3 shows the generating of left/right eye images. The depth cue that produces the stereoscopic effect is binocular disparity discussed above. However, it is possible for several depth cues to either reinforce 20 or conflict 22 with each other. The latter should be avoided when stereoscopic 3D virtual images are generated.

Figure 4 shows a parallel camera model 24 that is used in a preferred embodiment of the present invention. Nearly all computer displays are flat. Thus, the images projected on these displays are also flat. However, distortion can occur as we attempt to simulate the human eye, since the eye has a curved surface. The simple parallel camera model substantially removes distortion in projection, but there are 1) overlapping of the viewing spaces of the cameras is not always complete, which can cause a fraction of the image to be not stereoscopic, and 2) viewer is forced to converge his own eyes, since the cameras do not converge. The viewer having to keep focus on the monitor can cause a disparity between the depth cues of convergence and accommodation (changing of the focal lens of eyes to focus on an object). With practice, however, this disparity is not a problem.

In a preferred embodiment an active stereoscopic display is used for image presentation, where shutter glasses shutter on and off in synchrony, presenting one image at a time to each eye in quick succession while the other eye is covered. The switching

presentation is performed at 60 Hz so that the user "sees" only one stereoscopic image. When rendering a complex, dynamic, real time scene the images must be switched quickly enough or the stereoscopic effect would be lost. This problem is solved in a preferred embodiment by using the interlaced mode available on many video cards and a stencil buffer. Interlaced video displays only the even set of horizontal scan lines on a vertical scan followed by the odd set of scan lines on the next pass. This allows for smoother animation with a relatively low refresh rate as both the left and right eye images are displayed simultaneously on sequential vertical scans seen as one image, and the stereoscopic effect does not suffer. There is a concurrent loss of resolution that is not a problem since the brain merges the images and the resulting resolution is still acceptable. The stencil buffer is used to render the left eye images only on the even scan lines (on stencil), and the right eye image only on the odd scan lines (off stencil). This preferred embodiment minimizes the timing of switching the shutters on each vertical synch pulse from the display. The left eye image is on the screen during one entire vertical scan of even lines and the right eye is on the screen on the next vertical scan of odd lines.

The basic idea is to move the camera to the left and render the scene on stencil and then move the camera to the right and render off stencil. Then the right and the left eye images are interlaced together. When the video is placed in an interlaced mode, the result will be that the left eye image is displayed separately from the right eye image. The shutter glasses are automatically synchronized (as known in the art via a transmitter plugged into the output of the video card) to the vertical sync signals of the video card when in interlaced mode, the left eye will only see the left eye image and the right eye will only see the right eye image. Figure 5 shows a depiction of the scene of a turtle with the stencil on. Here, for example, only the even horizontal scan line of the interlaced video are present that are to be presented to the left eye in the example described herein. The right eye will be presented

with the odd horizontal scan lines coordinated by the video vertical retrace, synchronization or vertical blank signal associated.

Referring to Figure 6, the system is initialized 26 including a "callback" function that is used by the programmer to graphically render the haptic scene and ensure that the optical and haptic presentations and operations are coordinated, consistent and synchronized to each other. This task is well within the capabilities of those skilled in the art. The stencil and shape information is installed to accommodate the haptic and the two camera visual environment. The scene is 3D visually processed by moving the camera and turning the stencil on and off to create the visual 3D effect. The visual is then incorporated with the haptic in the main loop 26. Figure 7 indicates the independence of the 3D visual and the haptic interfaces. However, the combination is coordinated as described herein to present a realistic virtual scene with touch and sight. Although not discussed adding coordinated audio would enhance the present invention in particular applications. Such an addition and coordination are within the skill of the art when the present haptic/visual invention is disclosed.

The above techniques were applied in a preferred embodiment to an existing non-stereoscopic haptic scene. This haptic scene consists of several simple shapes that can be moved, rotated, translated and scaled. By applying the technique to the rendering function, it is possible for the user to view the scene stereoscopically using shutter glasses. The user also has the ability to dynamically adjust the perceived depth of the scene, and to control whether the objects appear to recess into the monitor or pop out of it. The user can view and feel the objects in three dimensions in real time. A simple stereoscopic haptic environment is finally created.

A preferred embodiment of the present invention included a 300 MHz personal computer running the NT operating system. The video was run at 43 Hz interlaced with



shutter glasses. Virtually any computing system, operating system and shutter glasses, known in the art, can be used in preferred embodiments of the present invention.

Although the invention has been described with respect to various embodiments, it should be realized this invention is also capable of a wide variety of further and other  
5 embodiments within the spirit and scope of the invention.

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